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NASA TECHNICAL TRANSLATION NASA TT F 15,676

A SYSTEM OF CONDITIONAL RELIEF SYMBOLS FOR LUNAR TOPOGRAPHIC MAPS

K. B. Shingareva and G. A. Burba

Translation of "Sistema uslovnykh znakov rel'yefa dlya lunnykh topograficheskikh planov," Institute of Space Research, Academy of Sciences, USSR, Report --- 152, Moscow, 1974, 26 pages.

(NASA-TT-F-15676) A SYSTEM OF CONDITIONAL RELIEF SYMBOLS FOR LUNAR TOPOGRAPHIC MAPS (Scientific Translation Service) ~~20~~ 26 p HC $4.50 CSCL 08B

N74-29726

Unclas
G3/13 54731

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 JULY 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F 15,676	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A SYSTEM OF CONDITIONAL RELIEF SYMBOLS FOR LUNAR TOPOGRAPHIC MAPS		5. Report Date July , 1974 6. Performing Organization Code
7. Author(s) K. B. Shingareva and G. A. Burba		8. Performing Organization Report No. 10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw-2483 13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Sistema uslovnykh znakov rel'efa dlya lunnykh topograficheskikh planov," Institute of Space Research, USSR Academy of Sciences, Report —/152, Moscow, 1974, 26 pages.

16. Abstract

Principles for the construction of a system of conditional relief symbols for lunar topographic maps are discussed. The system is based on a letter-number scheme of logical connections between relief elements. The possibility of altering the graphical symbols of this system, depending on what is required of the topographic map, is illustrated. Alternatives for designing topographic maps for the Lunokhod-1.

17. Key Words (Selected by Author(s))	18. Distribution Statement
	Unclassified - Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	26	

A SYSTEM OF CONDITIONAL RELIEF SYMBOLS FOR LUNAR TOPOGRAPHIC MAPS

K. B. Shingareva and G. A. Burba

The construction of detailed topographic maps for separate /3* sections of the lunar surface became possible rather recently. In 1966 — 1968, spacecraft of the Luna and Surveyor series transmitted to Earth after successful landings on the lunar surface a series of panoramas depicting relief imagery. The first topographic maps and diagrams were compiled as a result of the processing of these panoramas [1, 2, 3]. Their scales differed noticeably: from 1:20 and 1:40 on the Luna-9 and Luna-13 photographs to 1:100 — 1:500 on the Surveyor photographs. Significant differences were not observed in the content of the topographic maps and diagrams. The nature of the relief between craters was rendered by means of contour lines having a spacing of 5 — 10 cm. Craters, rocks, and, on some maps, lineaments were represented as separate elements. A stylized image of a shadow with a dot-dashed edge was used as the crater symbol, and a contour with a shadow or a filled contour was used to represent rocks. Relief elements are denoted by sequential numbering. One should note that the topographic map cited covered areas of the order of several hundreds of square meters directly adjacent to the spacecraft landing site. The problem of the detailed development of conditional symbols in the case of the representation of similar separate regions has not come up in practice; some relief elements (especially rocks) were represented on the map the same way as they appear on the panoramas. Such an

*Numbers in the margin indicate the pagination of the original foreign text.

individual representation of similar objects has arisen due to the fact that small areas were photographed and the data available to develop unique conditional symbols seemed to be insufficient.

The large-scale photography of the lunar surface which was carried out by Lunokhod-1 permits the compilation of topographic maps in an area of about 80,000 square meters [4]. Due to the dimensions of the territory photographed by Lunokhod-1, far more variety is observed on the panoramas in the way of relief elements in comparison with the prior situation on photographs taken by Luna-9, Luna-13, and the Surveyor [5]. This situation gives rise to an idea as to the advisability of introducing special conditional symbols for different relief elements. /4

The maintenance of uniformity and consistency in the conditional symbols is desirable in the compilation not of individual maps, but should be the goal of a sequential series. It should also be possible to introduce a conditional symbol for a new relief element discovered on the next panorama which fits right into the system of symbols already in use.

Along the same lines, the problem of designing a system of conditional symbols for lunar topographic maps seems rather timely. An alternative for such a system was developed at the Institute of Space Research of the USSR Academy of Sciences.

Bearing in mind the problem of compiling a topographic map (chart), its content must first be established. It is primarily determined by the purpose and scale of the map and also by a number of other factors, including the nature of the objects and phenomena depicted. The purpose of lunar topographic maps and diagrams is a most complete and detailed qualitative and

quantitative description by chartographic means of the Moon surface at large scales (greater than 1:10,000). This description should be as objective as possible. Only by the observance of the conditions outlined can the information of the topographic map be used for statistical calculations, in the analysis of the physico-mechanical properties of the soil, for solution of applied problems, and so on.

In contrast to the Earth, where a variety of factors are depicted on topographic maps and charts besides the relief such as the vegetation, hydrography, and the effects of human activity, for the Moon, the main and practically the only element of map content is the relief. /5

The depiction of relief is a characteristic case of the mapping of features of continuous extent for which the methods of contour lines and qualitative background are widely used. For example, contour lines serve as the main method for the quantitative relief characteristics on terrestrial general geographic maps; the method of qualitative background is widely applied for geomorphological maps, which characterize the relief with respect to origin, age, and other qualitative characteristics. Map makers have recourse to plastic methods of depicting relief in order to impart visualizability to the depiction. The reproduction of shadows corresponding to different relief elements creates the illusion of a convexity or a concavity. A similar effect is achieved in particular by means of washing — the application of shadows along the skeleton relief lines for a specified illumination, taking into account the representation in the contour lines. However, the addition to the contour lines of washing does not satisfy, as a rule, all the requirements imposed on the depictions of relief. A disadvantage of contour lines is their unsuitability for communicating "interruption of

the trend" — sharp deviations in the relief, such as crevices, ridges, and so on. In addition, they do not capture the microforms of relief and are poorly suited to the exhibition of those elements of it whose altitude is less than that established for the profile map. The contour lines intended for the essential features of the surface over its area are unsuitable for representing objects outside the scale, such as pits, mounds, and so on, even if their height exceeds the relief profile [6].

In representing lunar relief, the disadvantages enumerated above for contour lines appear still more pronounced than in the representation of terrestrial relief. In particular, the main relief element of the plains of the lunar maria are small craters /6 (from a few centimeters to a few thousands of meters in diameter). Representation of the relief by contour lines results in the fact that a large portion of the craters are not depicted in profile. The use of frequent enough profiles at the contemporary level of mapping is complicated by errors in determining the excesses. In addition, this approach results in a significant increase in the volume of work. The latter is most likely unjustified, since at the existing accuracy of determining the altitude of terrain points and in view of the well-known monotony of the lunar relief, whose main components are the craters, the monotony of the measurements to be carried out leads to an inconsistency between the volume of work and the proportion of useful information.

At this time, some quantitative characteristics of craters can be obtained with the use of deciphered signs of photographic images, which form the basis of a morphological classification of craters [7, 8]. The problem in mapping similar characteristics is solved by the introduction of conditional symbols. These symbols should distinguish objects not mapped by contour lines, i.e., not expressed in the "vertical scale" — the size of the

cross section. The use of symbols permits getting rid of the excessive breaking down of the scale for profile relief.

Since craters are at least the most widely distributed but by far not the only element of lunar relief, one should evidently pose the problem not of adopting individual special symbols but of planning a specific system of conditional symbols. The principles of designing an optimal system of symbols, which were used in setting up the proposed system, are outlined in [9]. By optimal system of symbols is understood a group of symbols having a logical interconnection in graphical representation and color /7
among all the conditional symbols and a complete consistency with the logical order of classification of the objects of chartography.

DESIGNING A SYSTEM OF CONDITIONAL SYMBOLS

The design of a system of conditional symbols contains two basic stages:

— the creation of a system of logical connections linking the majority of the elements of the map's or chart's content;

— the communication of the derived system of logical connections by a drawing and by color.

The maintenance of a system of logical connections in the design of the symbols in a diagram and in color improve the map's intelligibility, since memorization only of the system of constructing the symbols, and not of each individual symbol, is necessary in this case.

A System of Logical Connections of the Relief Elements

We will use a letter-number system of logical connections [9], which will, in our case, represent the abstract scheme of indexing the content of a topographic map. Such a system is suitable for transmitting specific information, since the letter-number symbols can be used directly on the map like the ordinary conventional symbols. The information transmitted in such a system can easily be transformed into a dual coding system. It can serve as the intermediary for the transition from one cartographic representation to another in case of the preparation of single maps based on others. The general form of the letter-number system of logical connections is presented in Figure 1.

	A	
Aa_1	Aa_2	Aa_n
$Aa_1b_1Aa_1b_2 \ldots Aa_1b_m$	$Aa_2b_1Aa_2b_2 \ldots Aa_2b_m$	$Aa_nb_1Aa_nb_2 \ldots Aa_nb_m$
$Aa_1c_1Aa_1c_2 \ldots Aa_1c_m$	$Aa_2c_1Aa_2c_2 \ldots Aa_2c_m$	$Aa_nc_1Aa_nc_2 \ldots Aa_nc_m$
$Aa_1d_1Aa_1d_2 \ldots Aa_1d_m$	$Aa_2d_1Aa_2d_2 \ldots Aa_2d_m$	$Aa_nd_1Aa_nd_2 \ldots Aa_nd_m$
$\ldots \ldots \ldots \ldots$	$\ldots \ldots \ldots \ldots$	$\ldots \ldots \ldots \ldots$
$Aa_1z_1Aa_1z_2 \ldots Aa_1z_m$	$Aa_2z_1Aa_2z_2 \ldots Aa_2z_m$	$Aa_nz_1Aa_nz_2 \ldots Aa_nz_m$

Figure 1. Letter-number system of logical connections [9].

As has already been pointed out above, what is being represented on the map is the relief (A). This is subdivided into the elements of lunar relief (Aa_i), whose dimensions are commensurable with the dimensions of the topographic map: craters (Aa_1), hollows (Aa_2), knolls (Aa_3), rocks (Aa_4), rilles (Aa_5), ridges (Aa_6), ledges (Aa_7), lineaments of an unclear nature (Aa_8), fields of small craters (Aa_9), fields of small knolls (Aa_{10}), fields of /9

small rocks (Aa_{11}), and fields of small fragments (Aa_{12}). One should understand by "small" objects which do not show up at the map scale (i.e., objects having a size less than 1 mm at the map scale). The most widely distributed features among the elements enumerated are the craters; their lunar relief is characterized by an amazing monotony mainly due to them. The other relief elements are encountered more seldom. Consequently, if one restricts the choice of symbols only according to the elements, the topographic map will represent mainly a monotonous collection of some uniform symbols or other denoting craters (for example, small circles). A topographic map having such content will contain little information.

As has already been remarked [10], the traditional principles of the cartography of the Earth cannot be used for the Moon without well-known alterations brought about by the uniqueness of the Moon surface and the methods of its investigation. Thus, it is necessary, on the general geographic and topographic maps of the Earth, to limit the number of characteristics of each element of content (relief, vegetation, hydrography, and so on) in order to avoid the overloading which arises as a result of the variety of terrestrial nature reflected in the map. Since, on the Moon, practically the only element of the content of topographic maps and charts is the relief, it seems possible to enrich the content of relief depiction. The large number of relief characteristics on a lunar topographic map causes it to approach in content the thematic maps of terrestrial relief. The latter will introduce certain changes in the concept "topographic map" applicable to the Moon.

The question arises as to what criteria one can propose to characterize the enumerated relief elements in order to enrich the content of the topographic map while, at the same time, not /10

introducing excessively subjective evaluations. In this respect, the inclusion of classifications based on genetic symbols is extremely undesirable: For example, the division of the relief elements into young and old, into elements of volcanic and impact origin, and so forth. Data of such a nature should be reflected on thematic maps; regarding topographic maps and charts, one must seek other symbols to enrich their informational content.

Below are presented such objective characteristics of the relief elements:

— the maximum characteristic steepness of the slope (d) — Aa_ib_j,

— geometric shape of the bottom, base — Aa_ic_k,

— relative sizes (the ratio of a crater depth to its diameter, H/D, the ratio of a rock height to the length of its base, h/d, and so forth) — Aa_id_m,

— peculiarities (the presence of an embankment in a crater) — Aa_ie_n.

It should be immediately stipulated that, at the present time, it is possible to cite exact quantitative characteristics of just a few of the relief elements enumerated, since the degree of their investigation is not the same. However, a suitable choice of symbols permits the fundamental development of the system in the future. In addition, one can use a more general preliminary division at the initial stage for some elements.

Let us discuss further how the relief elements enumerated above are classified taking into account the selective symbols (Figure 2). Data given in [8] were used in the selection for

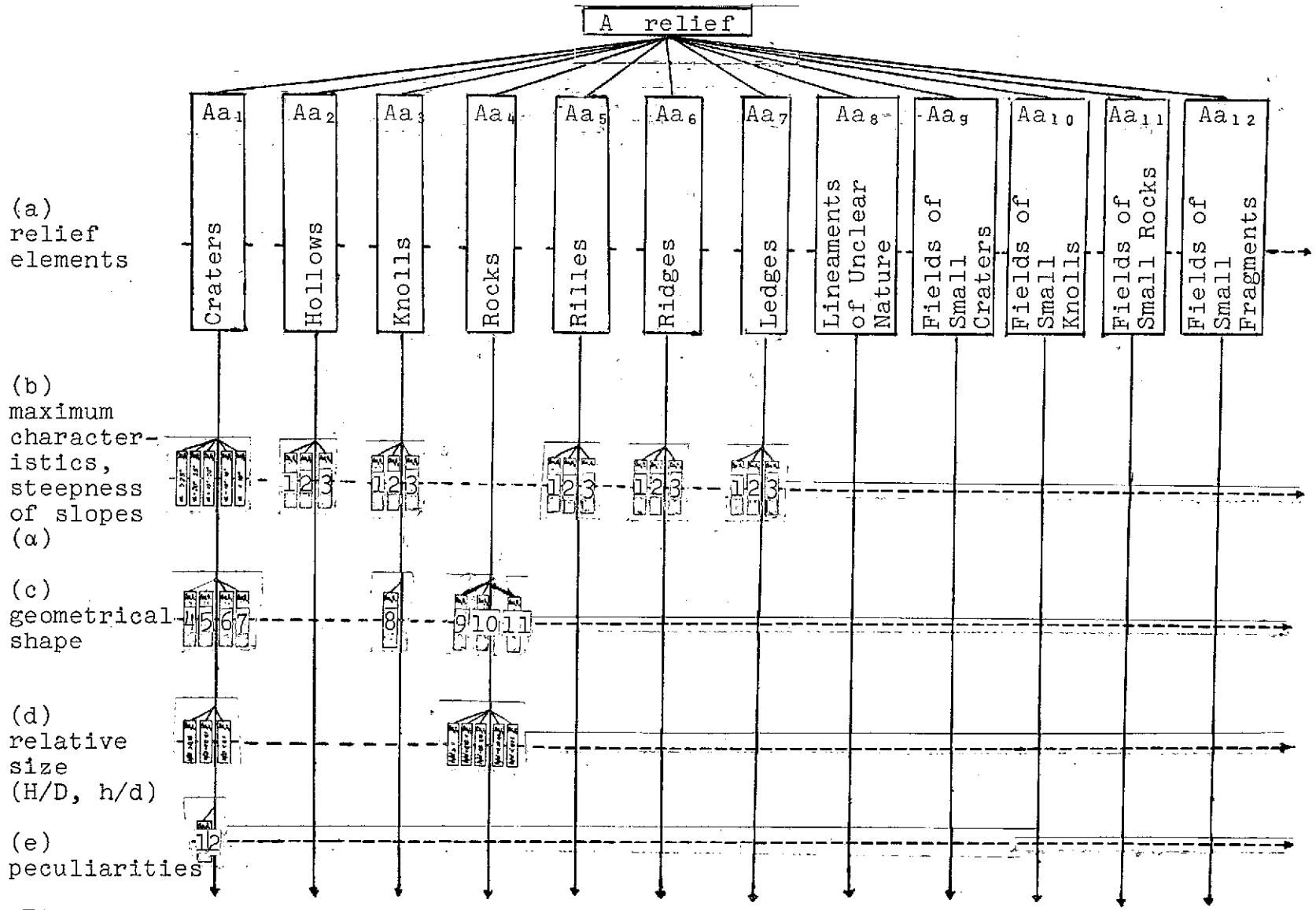

Figure 2. Scheme of logical connections between relief elements.

1- steeply sloping; 2- average steepness; 3- gently sloping; 4- conical; 5- less conical; 6- flat bottomed; 7- [illegible]; 8- dome; 9- angular; 10- less angular; 11- rounded or smooth; 12- presence of an embankment.

craters of the scales of the division with respect to the steepness of slopes (d) and with respect to the ratio of crater depth to diameter (H/D). The preliminary division of the slopes of a number of relief elements into steep, average steepness, and gently sloping is provided for by coding symbols, but it does not contain an accurate quantitative estimate. The adopted /11 shapes of craters are described in [8]. The conditional division according to shape for rocks is taken from [11].

It follows from Figure 2 that the classification which is possible at the present stage seems far from complete and in need of further improvement. Therefore, it is necessary in the graphical representation in the conditional symbols of the derived logical connections to keep in mind the possibility of introducing supplementary symbols without disrupting the logic of the system construction.

Communication of the System of Logical Connections by a Drawing and by Color

The graphical version of the proposed system of conditional symbols is presented in Figure 3.

The relief elements were divided into three groups in the representation of the logical connections in a drawing:

1. Elements with a closed outline (craters, hollows, knolls, rocks);

2. Linear elements (rilles, ridges, ledges, lineaments of an unclear nature); and,

3. Elements of area coverage (fields of small craters, knolls, rocks, fragments).

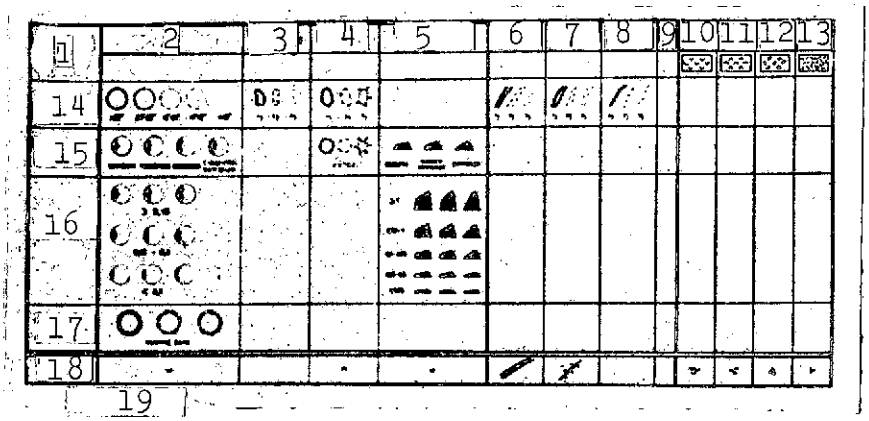

Figure 3. Graphical representation of the relief elements reflecting the logical connections among them.

1- relief elements; 2- craters; 3- hollows; 4- knolls; 5- rocks; 6- rilles; 7- ridges; 8- ledges; 9- lineaments of an unclear nature; 10- fields of small craters; 11- fields of small knolls; 12- fields of small rocks; 13- fields of small fragments; 14- maximum characteristic steepness of slope (α); 15- geometrical shape; 16- relative size (H/D, h/d); 17- peculiarities; 18- [illegible]; 19- [illegible]; [Translator's note: Balance of table illegible in foreign text].

The object outline is given for relief elements of the first group: along the edge for craters and hollows, along the base for knolls; rocks are represented by a stylized silhouette. In addition, spiked lines are added for hollows and knolls. The introduction of spiked lines for the crater symbol is considered inadvisable, since craters are the predominant relief element and the definition of a crater is well known.

The steepness of the slopes of the relief elements enumerated above is communicated by a symbol constructed according to the degree of relative intermittency of the line delineating its outline. A more intermittent line corresponds to less steepness of the slopes. In order to distinguish the steepest relief /14

elements, a thinning-out of the line by a factor of two relative to the symbols representing more gentle slopes is adopted for the outlines corresponding to slopes of the order of 20° and greater. The use of various combinations of dashed lines and dots to represent the intermittence of a line has led to the construction of a graphic scale which permits the introduction in the future of additional gradations.

Since the shape of a shadow is associated with the shape of craters, the representation of a shadow was used as the conditional symbol for communicating a crater shape. A stylized image is provided by means of sparse cross hatching.

The relative dimensions of a crater (H/D) are represented by the size of the symbol for the crater shape. The larger the relative depth, the wider is the symbol for the crater shape (shadow).

The presence of an embankment in a crater is shown by drawing a second line reiterating the main line on the drawing and parallel on the outer side to the edge's line. The thickness of the second line is one-half the main line thickness. The distance between them is arbitrary and equal to the thickness of the main line. The symbol does not indicate the outer boundary of the embankment, the exact determination of which does not yet appear possible in view of the gradualness of the transition into the surrounding surface (the embankment may have a width of 0.2 to 0.5 of the crater diameter). Such a representation of an embankment does not seem quite successful, since it does not illustrate the region occupied by the embankment but only indicates the presence of the latter. The indication of the area occupied by an embankment is achieved only by means of washing (shading). The introduction of some kind of area symbol which shows the

region of an embankment and its gradual transition into the inter-crater surface is possible in an alternative without washing (shading).

Domes, which represent knolls of regular shape, are illustrated by the same symbol as knolls are. The difference consists solely of the fact that the outline has the shape of a circle. /15

A stylized outline is selected to represent individual rocks. The rock symbol is cross hatched. The cross hatching slope amounts to 45°, the thickness of the lines is 0.1 mm, and the interval between lines is 0.2 mm. The cross hatching of the rock symbol is represented preferably by a solid filling-in, since with the latter rocks are too sharply distinguished from the general background, hindering the perception of other relief elements. Filling an outline with points produces the illusion of a first-hand drawing of a rock which does not correspond to reality.

The differences in the shape of rocks (in the degree of their angularities) are communicated by a combination of broken and smooth contour lines.

In order to communicate the height of rocks, whose base length is expressed in the map scale, a scale of the ratios of the rock height to the length of its base (h/d), which is represented by the relative height of the symbol, is selected.

A spiked line is introduced as the symbol for the second group of relief elements. The different combinations of lines and spikes permitted compiling a series of symbols. Just as for craters, the steepness of the slope is communicated by the degree of intermittency of the lines.

In order to represent area coverage (the third group of relief elements) out-of-scale crater, knoll, and rock symbols are used. A collection of small fragments is illustrated by a degenerate out-of-scale rock symbol. The boundaries of fields are shown by a brown dotted line. A sharp boundary is indicated by a dotted line with an equal interval between points, and a gradual boundary is indicated by a dotted line with omissions.

In order to represent relief elements not expressed at the scale (which have a size less than 1 mm), out-of-scale symbols /16 are introduced. Out-of-scale relief elements are represented selectively on a map only in the individual cases in which it is necessary to illustrate some kind of characteristic features consisting of small elements (for example, chains of small rocks or craters).

A stylized profile image of a crater, knoll, or rock is used as the out-of-scale symbol for relief elements of the first group. The little symbol has a size of 1 mm along its longest axis. An out-of-scale symbol is not introduced for hollows of irregular shapes, since this relief element is not widely distributed. One can use the crater symbol in a case of necessity.

In the second group of relief elements, an out-of-scale symbol is introduced for rilles and ridges having a width not expressed at the map scale. Rilles are represented by two parallel lines which are joined by spikes. The distance between the lines is 0.5 mm. Ridges are shown as a single line with spikes on both sides.

Fields whose area is not expressed at the map scale are represented by a contrived out-of-scale symbol corresponding to the relief element.

The color of conditional symbols is useful for creating a definite association, thereby permitting a clearer representation of the phenomenon being mapped. However, the correspondence of a single color to a specific group of symbols is not always maintained on terrestrial topographic maps. The establishment of complete logical correspondence for terrestrial topographic maps is complicated by the variety of factors represented and also by the traditions of the representation of specific objects. It seems possible to work out for the Moon a unique scheme of the use of color on topographic maps and charts.

On the topographic maps based on the Luna-5 and Luna-13 photographs [1, 2], craters and contour lines are shown in brown; /17 rocks, ridges, and lineaments are shown in drak brown; station details are shown in red; and the grid and captions of the objects are shown in blue. All topographic maps based on the Surveyor photographs [3] are executed in black-and-white.

It is proposed to use black for the conditional symbols of all the relief elements. The characteristics of the relief which are not directly observable in the form in which they are represented on the map (contour lines, altitude marks, boundaries of fields, and so on) will be shown in brown.

The black and brown colors are the traditional colors for relief on terrestrial topographic maps and, in addition, they are similar to the natural color of the Moon surface. It is proposed to present the washing (shading) of the relief on the lunar topographic maps in brown. Such a background for a map emphasizing

the easy visibility of the relief will not simultaneously weaken the conditional symbols shown in black.

In order to show phenomena of human activity, colors of the red range are the most suitable, since such phenomena are unique on the Moon surface and one should distinguish them on maps and charts. Artificial structures (buildings, spacecraft) will be shown in yellow. Artificial relief shapes (ruts, footprints in the soil, disruption of the relief at the sites of sample collection) will be shown in orange or reddish-brown. The latter will associate artificial relief shapes with natural ones represented by brown and black.

The notations by objects (names, numbers, and so on) should be given in the same color as the objects themselves. This practice will improve the legibility of the maps and exclude possible misreading of the notations.

The use on topographic maps and charts of the Moon of blue and green is thought to be inadvisable. These traditional colors, /18 which are associated with hydrography and vegetation, would produce an incorrect notion as to the nature of the phenomena represented.

Possibility of Altering the Standard Scale of Symbols

The advantage of the present system of conditional symbols consists of the fact that it permits expanding and contracting the scale of the symbols, depending on the requirements for this or that information. The system itself is not disturbed by such a change, because the added symbols are not arbitrary; they are logically interrelated with the remaining symbols. Thus, in case of the necessity to represent the density of fields of craters,

knolls, rocks, and fragments, a symbol for a field of variable density can be introduced by an image of a variable number of symbols per unit area (Figure 4a). Rocks which have peculiarities (sharply different color, structure, composition, and so forth) can be distinguished by a thicker dashed line or by the filling-in of the contour (Figure 4b). Supplementary gradations with respect to the steepness of slopes can be represented by the use of various combinations of dashed lines and points in the drawing of a line and also by a different thickness of the contour lines.

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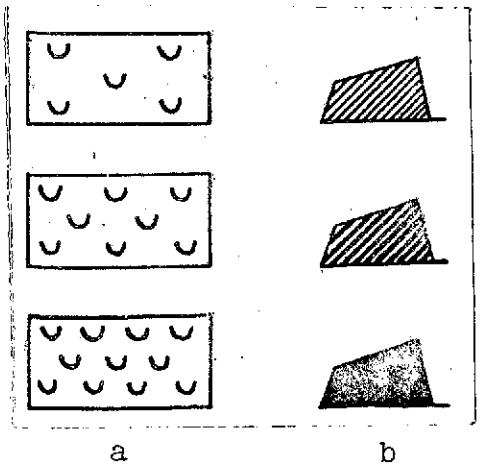

Figure 4. An example of the alteration of the typical scale of symbols.

In the proposed system, logical connections between the conditional symbols, which are expressed in the drawing and the color of the symbols, correspond to this or that extent to the logical connections between the imaged objects themselves.

MODELS OF TOPOGRAPHIC MAPS ILLUSTRATING THE PROPOSED SYSTEM

The development of the conditional symbols was carried out on a map scale of 1:100. Two panoramas transmitted by Lunokhod-1 comprising a stereo pair were laid out of the basis of this map. However, the plan entirely carried out should be considered as an illustration of the system of conditional symbols. This is because there are present individual relief elements on the map which are absent on the actual stereo panorama. The models for the layout of the topographic map in the proposed system of conditional symbols are shown in Figures 5, 6, and 7 (see the conditional notations in Figure 3).

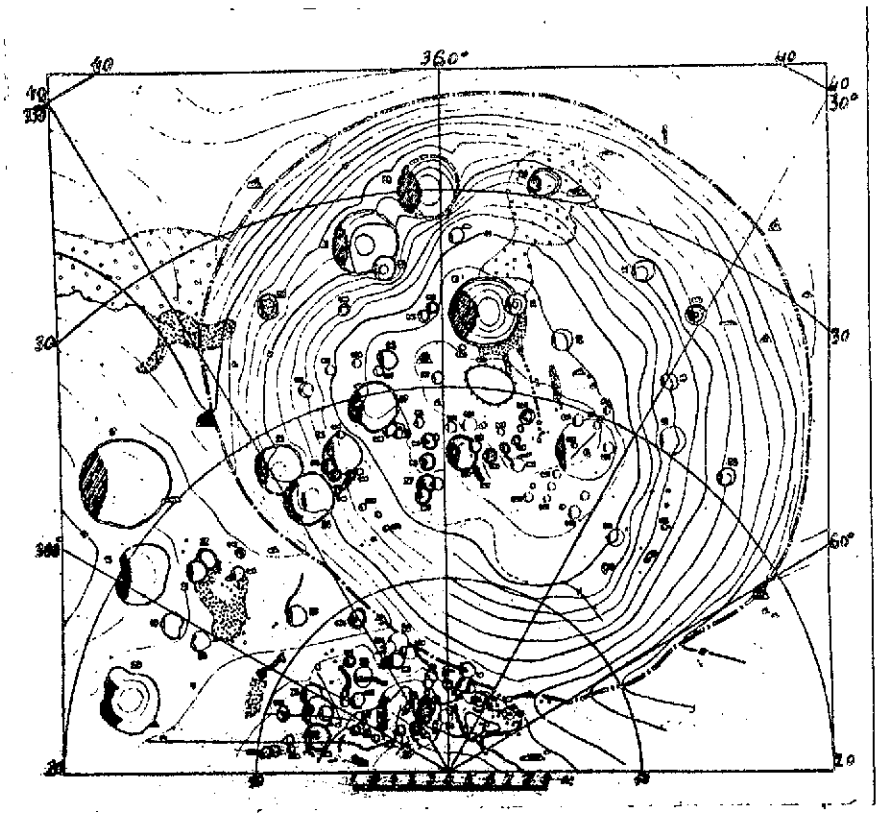

Figure 5. Model of the layout of the topographic map with the representation of relief by contour lines and conditional symbols.

It is impossible to derive a representation of the surface with the identical detail at various distances (as it occurs on vertical photographs), since Lunokhod-1 carried out oblique panoramic photography. The dependence of the codability of craters of various size and morphological class on their distance to the television camera of Lunokhod-1 is cited in [12]. The minimum size of objects visible increases as the distance to the television camera increases. The great detail of the map near the center of the panorama is explained by this fact.

The television camera is mounted at the center of the lower /20 frame of the map. The concentric grid lines show the distance of objects from the camera, and the radial lines denote the

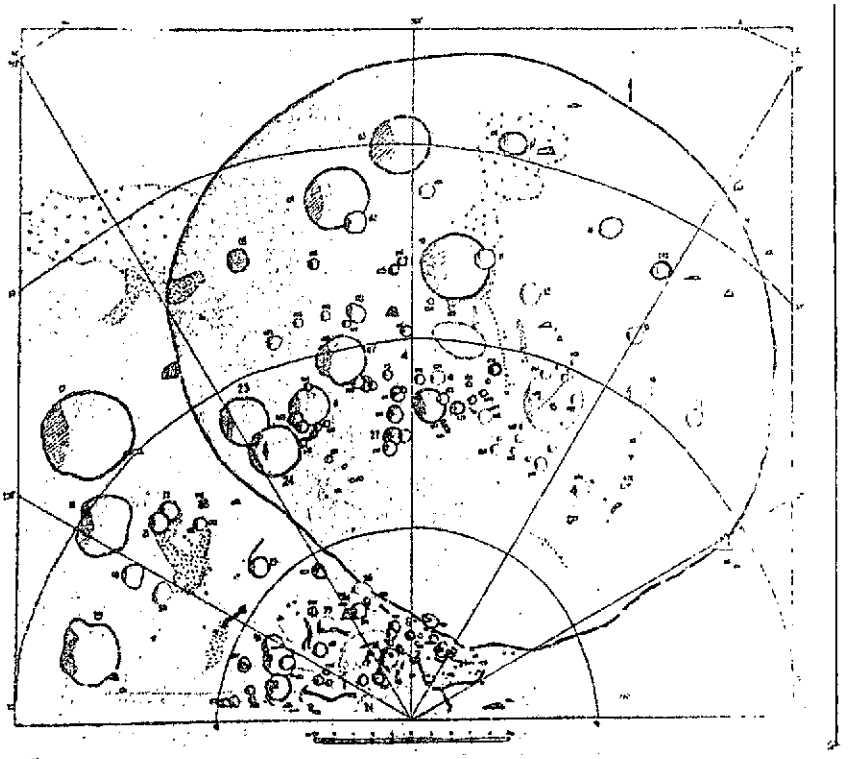

Figure 6. Model for the layout of the topographic map with the representation of relief by conditional symbols and washing or shading (the washing is done sketchily).

directions from it. Such a grid, which is suitable for single maps, should be replaced in the production of a series of maps by a grid of selenographic coordinates which provides a connection among all the maps.

The principle of numeration described in [13] is used to designate craters. Craters are divided into groups according to their diameters (D) and are denoted by a single-valued, double-valued, and so on, number, depending on their group:

$$D > 10 \text{ m} — 1, 2, \ldots, 9$$
$$1 \text{ m} < D < 10 \text{ m} — 01, 02, \ldots, 99$$
$$D < 1 \text{ m} — 001, 002, \ldots, 999.$$

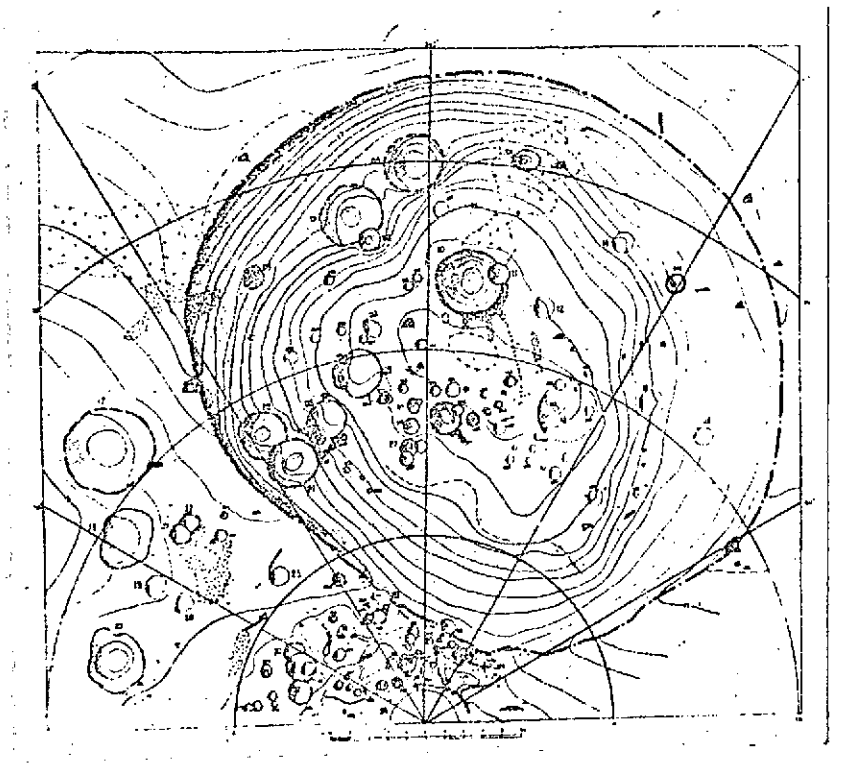

Figure 7. Model of the layout of the topographic map with the representation of relief by contour lines, conditional symbols, and washing or shading (the washing is done sketchily).

The numeration was carried out on lines 10 m in width from left to right, starting from the northwest corner of the map. Type of various size is used in accordance with the size group of the craters. The notations to craters on the map are given selectively in order not to overload it. The designations for unnumbered craters can easily be established by "interpolation" between the numbers of the nearest marked craters within the limits of a given line according to the direction left-to-right. In order to tie in details to a specific region, one can add to the detail number a digit which denotes the number of the Lunokhod-1 station. The other relief details are not numbered. Their numeration can be carried out according to an analogous system, since one can use various types for the different relief elements.

Such a system of notations permits easily determining the number of craters in a region both with respect to each size group and the total (based on the largest numbers in the group and the sum of these numbers). This makes it possible to obtain without carrying out computated calculations a preliminary density /22 of the craters for the different groups which is necessary to estimate the terrain (roughness) and certain other characteristics of the surface.

An analysis of a model of the topographic map (Figure 5) shows that representation of lunar relief with the help of the assumed system of conditional symbols possesses the quality of the three types necessary for a cartographic map [9]:

1. It provides for the derivation of data about the mutual arrangement of objects on the Moon surface based on the mutual arrangement of the images of these objects on the map.

2. It permits the rather easy identification of objects according to an image resembling their external appearance.

3. It communicates the differences in the quantitative and qualitative characteristics of the objects by visually perceptible distances in the images of these characteristics on the maps.

The symbols for relief elements form various combinations on the map. In agreement with the requirements of clear representation of the third kind to provide a high legibility, it is necessary that the image be perceived in a definite sequence corresponding to the importance of the object. The proposed system of conditional symbols satisfies this requirement. The greatest line width and continuity, which provides the image of these objects on the first map, is used to represent the steepest

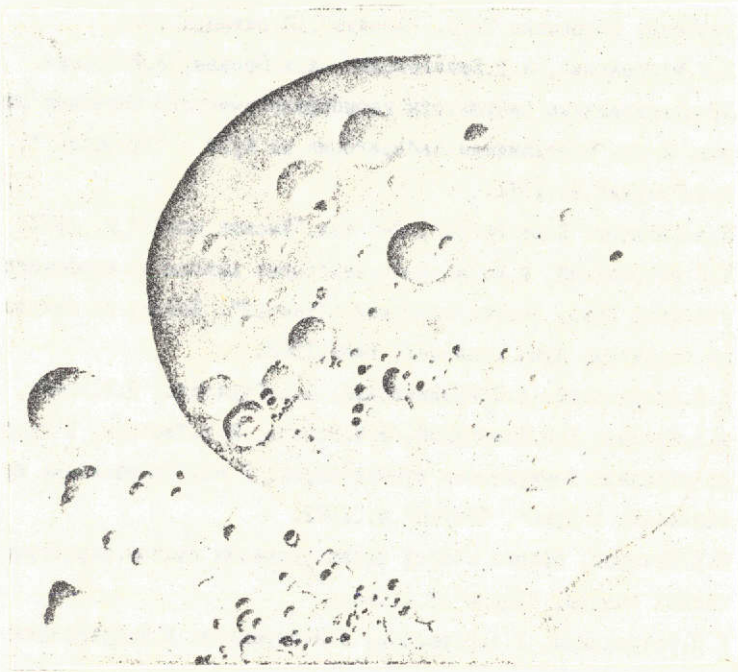

Figure 8. Model of relief washing (shading).

relief elements, which are sharply localized. The symbols for the relief elements of average steepness have a thinner and more discontinuous outline, creating the representation of the second map. The most gently sloping elements make up the third map, which is achieved by the use of a dotted line. The representation of rocks, which differs from the representation of other relief elements, also corresponds to the requirements of order and clarity of perception.*

*[Translator's Note: The remainder of the foreign text has been omitted.]

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Translated for National Aeronautics and Space Administration under Contract No. NASw-2483, by SCITRAN, P. O. Box 5456, Santa Barbara, California 93108.